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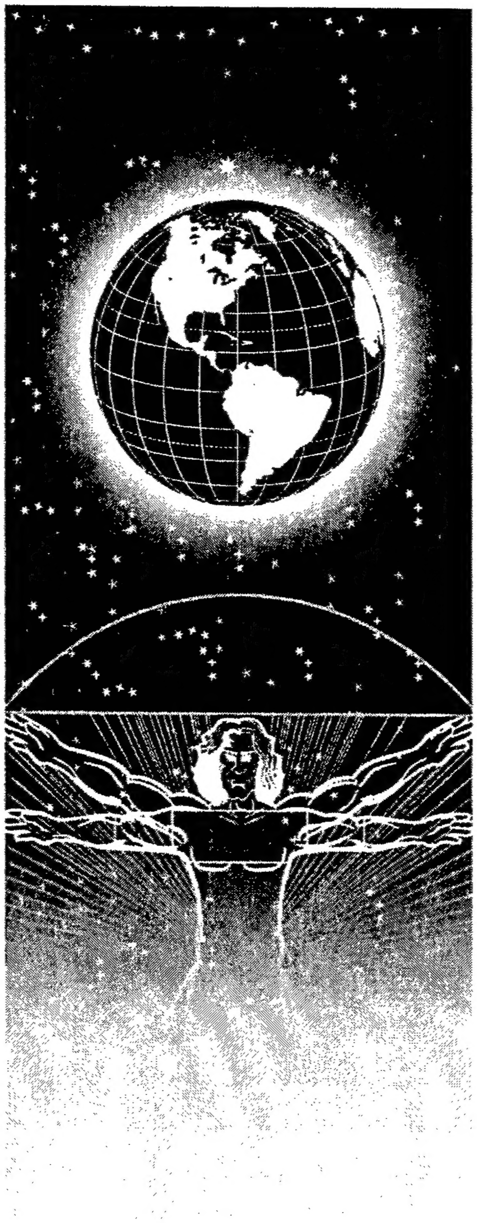

UNITED STATES AIR FORCE RESEARCH LABORATORY

66 MM NON-LETHAL GRENADE: HUMAN EFFECTS REVIEW

Daniel L. Gonzalez
Roxanne Constable

Conceptual MindWorks, Inc.
4318 Woodcock Dr., Ste. 210
San Antonio, TX 78228

Thomas Dayton

Veridian Engineering
PO Box 35505
Brooks City-Base, TX 78235

Jeff Widder

Batelle
2012 Tollgate Rd., Ste. 206
Bel Air, MD 21015

B. Jon Klauenberg

HUMAN EFFECTIVENESS DIRECTORATE
DIRECTED ENERGY BIOEFFECTS DIVISION
RADIOFREQUENCY RADIATION BRANCH
8262 HAWKS ROAD
Brooks City-Base, Tx 78235-5147

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B. JON KLAUENBERG, Ph.D.
Contract Monitor

RICHARD MILLER, Ph.D.
Chief, Directed Energy Bioeffects Division

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Conceptual Mindworks, Inc.	Veridian Engineering	Batelle
4318 Woodcock Dr. Ste 210	PO Box 35505	2012 Tollgate Rd., Ste.206
San Antonio, TX 78228	Brooks City-Base, TX 78235	Bel Air, MD 21015

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Human Effectiveness Directorate
Directed Energy Bioeffects Division
Joint Non-Lethal Weapons Human Effects Center of Excellence
8262 Hawks Road
Brooks AFB TX 78235-5147

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14. ABSTRACT
The purpose of this report is to assess the target effectiveness and the risks of severe (unacceptable) injury to those individuals who are impacted by the 66mm Non-Lethal Grenades (NLG) submunitions or projectiles (specifically the XM99 and the XM98) from the data in the literature and experimental data collected during development of the system. The XM98 is a distraction grenade that uses a pyrotechnic charge for crowd control through auditory and visual stimuli. The XM99 is a blunt trauma grenade that uses a pyrotechnic charge to discharge 0.32 cal rubber balls and achieve crowd control through audio, visual, and physical stimuli. (Submunition refers to one of the 125g canisters that comprise the 66mm NLG. Projectile refers to one of the 0.32 caliber, 0.4g balls dispensed from the XM99 submunition.) The 66mm NLG will be capable of being fired by all currently fielded 66mm grenade launchers, primarily the Light Vehicle Obscuration Smoke System (LVOSS) 66mm M7.

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Executive Summary

1 OBJECTIVE

The purpose of this document is to provide to the Joint Non-Lethal Weapons Program (JNLWP) Human Effects Review Board (HERB) a review of existing data on the Human Effects (HE) of the 66mm Non-Lethal Grenade (NLG) system. Based on current data, this document will also serve as a summary of the system performance and related target effectiveness of the 66mm NLG.

2 ASSUMPTIONS

2.1 The worst-case (conservative) scenario is that all targets are immobile and facing the shooter.

2.2 The target is wearing a single layer of clothing.

3 SYSTEM INFORMATION

The 66mm NLG are munitions launched from the Light Vehicle Obscuration Smoke System (LVOSS) 66mm M7. The operational requirement is that the 66mm NLG be effective at a distance of 100 meters (with an objective range of 120 meters). They are intended to be indirect fire, low hazard, non-shrapnel-producing grenades employed as a non-lethal counter-personnel weapon. The 66mm NLG are designed to enhance force protection by stopping, confusing, disorienting, or deterring a potential threat through startle (flash-bang) and/or skin pain caused by blunt impact.

4 SYSTEM EFFECTIVENESS

The available data on system target effectiveness are extremely limited. Most of the data described in models and reports reviewed herein are based on either lethal projectile studies or on large, high mass, low velocity, and noncompliant projectiles.

Because of the variability in the accuracy and dispersion of the 66mm NLG, it is very likely that someone in the crowd will be impacted by an unexploded submunition. Predicted injuries from an unexploded submunition include a 21% chance of slight lung contusion and a 1% chance of a skull fracture at 50 meters. These probabilities will be expected to decrease as the distance increases beyond 50 meters. There is also a 1% chance of causing mandibular fractures at 50, 75, and 100 meters. Furthermore, the Total Body Model (TBM) predicts possibility of skull injuries, moderate lung contusion, ventricular fibrillation, and liver laceration at distances less than 60 meters. At distances greater than 60 meters, only mandibular fracture and trace to slight lung contusion is expected.

Although the system may perform as described in the Operational Requirements Document (ORD) at the proper distances, it is uncertain whether the original objective will be met, i.e. dispersing a crowd. Behavioral responses caused by a physiological

stimulus (e.g. pain induced from the 66mm NLG 0.32 caliber projectile or startle from the flash-bang effect) have yet to be measured or determined.

5 SAFETY ISSUES

5.1 Risks to the target from the submunition include the potential for blunt trauma, skin damage, and eye trauma, and are strongly dependent on the range to the target, the area of the body impacted, and the thickness of clothing at the point of impact. Blunt trauma models predict that the effects of a single impact are relevant because it is likely that someone in the target will be impacted by an unexploded submunition.

5.2 Impacts by the dispensed rubber balls (projectiles) will not likely penetrate into tissues below the skin. The impact velocity of the dispensed balls of 88m/sec is below the threshold impact velocity of 227m/sec (20.6J/cm^2) necessary for penetration of skin. (However, these skin penetration data that form the basis for the 20.6J/cm^2 are based on one study[9] of projectiles designed to be penetrating and lethal and not rubber balls).

5.3 Penetration of the eye by a projectile is not likely at any of the ORD defined operational ranges. If the submunition bursts while standing on its end, a child has a 2% chance of an eye impact by the projectile at 5ft. (1.5m), while a group of ten children have an almost 20% chance that one of them will suffer an eye impact. An adult, however, has less than a 1% chance of an eye impact by the projectile at 10ft. (3m), while a group of 10 adults have just over a 6% chance that one of them will suffer an eye impact. If the submunition bursts while lying on its side, a child has a 6% chance of an eye impact at 1.3ft. (0.4m). At the same distance, the risk exceeds 35% for a group of 10 children. An adult, however, has a 2% chance of an eye impact at the same distance, while the risk is almost 18% for a group of 10 adults.

5.4 Although risks to the target do exist, most of the risks are minimal, with the exception of eye injury, which is estimated to range from minimal to severe.

RECOMMENDATIONS & OUTSTANDING ISSUES

<u>Recommendation #1:</u> Measures of effectiveness on target behavior need to be determined. Responses of human test subjects need to be evaluated. Tests should first be conducted using animal surrogate models to determine behavioral effects of hits and impact velocities obtained at operationally relevant distances.

The 66mm NLG is designed to change a target's behavior. The limited available data address health risks, but not target effectiveness. To do so requires measuring some behavioral response caused by a physiological stimulus, such as the pain caused by impact of the 0.32 caliber submunitions. This type of effectiveness data on targets has not been collected for the 66mm NLG. It is noteworthy that this type of data has not been collected for most proposed non-lethal blunt impact weapons.

Recommendation #2: Crowd behavior data need to be studied or collected.

An assumption made by Dr. Widder to estimate probabilities of eye impacts is that 100% of the crowd faced the shooter and was immobile. This, of course, is worst-case for the 95th percentile male. To "tighten up", or better estimate the probabilities, one would need to have a better handle on the crowd dynamics. Modeling crowd behavior may be even more important if one changes the mix of the crowd (i.e., women and children whose eyes are closer to the ground in a more dense dispersion area).

Recommendation #3: Modes of injury and the measures of effectiveness on target should be estimated or identified early in the acquisition cycle and should match the requirements of the human effects measures of effectiveness. It is recognized that the 66mm NLG acquisition is a legacy system that progressed rapidly past this point without definitive guidance on defining and collecting HE data. In the future, tests or experiments that collect data to determine probabilities of injury and effectiveness should be incorporated into the Test and Evaluation Master Plan (TEMP). Furthermore, additional 'arena' testing is needed to determine the dispersion for further eye impact probability calculations.

The potential for eye damage will be a concern for all kinetic munitions. Sufficient dispersion data are required at the ranges of interest to estimate the probability of eye impact. Collection of data relevant to the assessment of effectiveness and safety could be piggybacked on planned system performance tests. For example, during the 'arena' tests, eye sockets could have been drawn in the anatomically correct positions on the silhouettes and hits recorded per number of submunitions fired. A significant portion of data relevant to human effects review can be acquired during planned system performance testing, if the JNLW HECOE is consulted while designing the TEMP.

Recommendation #4: The models used to perform human effects assessments, such as the Total Body Model, need to be validated with actual test data to show that they extend to the projectile characteristics of the 66mm NLG 0.32 cal submunition (low mass, high velocity, compliant).

Recommendation #5: Information concerning the variables/parameters affecting the performance of the 66mm NLG could be added to the Joint Munitions Effectiveness Manual (JMEM) and/or could be included in a Non-Lethal Weapons Effectiveness/Use Manual. These manuals could be updated as information on effectiveness and injury is gained from in field experience with the 66mm NLG.

The likely percentage of injured persons and the severity of the injuries will be strongly influenced by the situation. The distance from the target, the aim point, the size, physical condition, and age of the crowd members targeted are some of the parameters that will influence the severity and number of likely injuries.

SOURCES OF INFORMATION

- System Information Sheets
- Cross Sectional views from the Technical Data Packages
- Integrated Program Summary for 66mm Non-Lethal Grenade
- Operational Requirements Document (ORD) for the Light Vehicle Obscuration Smoke System (LVOSS)
- Operational Mode Summary/Mission Profile (OMS/MP) for the 66mm Non-Lethal Grenades
- Charts Depicting Predicted Impact, Actual Impacts, and Roll Distances for the XM315 LVOSS Installation Kit
- Predicted Launch Angle and Elevation Requirements
- XM98/99 Vertical Wind Tunnel Test Results
- Data Report for the Test of the LVOSS Adjustable Elevation Bracket for the M7 Discharger
- Theoretical Stingball Velocity Decay Profiles
- Calibration Procedure to Indirectly Measure Stingball Impact Velocity
- Health Hazard Assessment (HHA) Report on the XM98 and XM99 66mm Non-Lethal Grenades
- 66mm, XM98 Non-Lethal Grenade Blast Overpressure/Noise Tests
- Non-Ionizing Radiation Protection Study/Optical Radiation Hazards from the 66mm Grenade Launcher and XM98/99 Canisters
- Engineering Development and Production Qualification Test (PQT) Matrices
- Final Report for the Accuracy/Dispersion Test of the Non-Lethal Ammunition
- Summary Report of Protocol Entitled: 66mm Vehicle Launched Non-Lethal Grenade "Distinguish-ability" Study
- 66mm Non-Lethal Blunt Trauma (XM99) Grenade Skin Penetration Analysis
- 66mm Non-Lethal Blunt Trauma (XM99) Grenade Eye Injury Analysis
- System Evaluation Report (SER) of the 66mm XM98 Distraction and XM99 Blunt Trauma Grenades/Cartridges
- 66mm Non-Lethal Distraction (XM98) and Blunt Trauma (XM99) Grenade Lethality Analysis Plan
- Supportability Strategy for the LVOSS: 66MM vehicle Launched Non-Lethal Grenades (Blunt Trauma and Distraction)
- Combat Developer Reliability and Maintainability (R&M) Analysis for the Non-Lethal LVOSS
- Test and Evaluation Master Plan (TEMP) for the XM98 66mm Distraction Grenade and XM99 66mm Blunt Trauma Grenade
- Concept Of Employment (COE) for the LVOSS
- INTERIM REPORT: Preliminary Effort to Identify Mechanical and Geometric Parameters that Govern Pain From Non-Penetrating Projectile Impact, Mission Research Corporation
- Non-Lethal Joint Operational Excursion Final Test Report
- HEAP's Report of Findings: The 66mm Non-Lethal Grenade

1.0 Introduction

The purpose of this report is to assess the target effectiveness and the risks of severe (unacceptable) injury to those individuals who are impacted by the 66mm Non-Lethal Grenades (NLG) submunitions or projectiles (specifically the XM99 and the XM98) from the data in the literature and experimental data collected during development of the system. The XM98 is a distraction grenade that uses a pyrotechnic charge for crowd control through auditory and visual stimuli. The XM99 is a blunt trauma grenade that uses a pyrotechnic charge to discharge 0.32 cal rubber balls and achieve crowd control through audio, visual, and physical stimuli. (Submunition refers to one of the 125g canisters that comprise the 66mm NLG. Projectile refers to one of the 0.32 caliber, 0.4g balls dispensed from the XM99 submunition.) The 66mm NLG will be capable of being fired by all currently fielded 66mm grenade launchers, primarily the Light Vehicle Obscuration Smoke System (LVOSS) 66mm M7.

According to the Operational Requirements Document (ORD), the system will be used during Military Operations Other Than War (MOOTW). The 66mm NLG will enable friendly forces to enhance the capability to conduct force protection by stopping confusing, disorienting, or deterring a potential threat and are intended to be deployed as indirect fire, low hazard, non-shrapnel producing grenades which will produce a non-lethal anti-personnel effect. These payloads will provide time for friendly forces to maintain the initiative.

To do this assessment, historical and state-of-the-art models and thresholds for blunt trauma, acoustic impulse, thermal and spectral injury were reviewed and used. Injury is predicted for a small percent of the persons against whom the 66mm NLG is used. To determine if use of the 66mm NLG is a proportional response, as outlined by the rules of engagement (ROE) and in DoD Directive 3000.3 Policy for Non-Lethal Weapons (E.6.d(1)), commanders in the field need to know the risk and severity of injury in advance of using the system. These estimates will also help the weapon system pass international scrutiny. The likely percentage of injured persons and the severity of the injuries will be strongly influenced by the situation. The distance from the target, the aim point, the size, physical condition, and age of the crowd members targeted are some of the parameters that will influence the severity and number of likely injuries. This information could be added to the Joint Munitions Effectiveness Manual (JMEM) and/or could be included in a Non-Lethal Weapons Effectiveness/Use Manual. These manuals could be updated as information on effectiveness and injury is gained from in field experience with the 66mm NLG.

2.0 Types of Injury

The principle mechanism by which the 66mm NLGs are expected to achieve their desired effect is by blunt trauma caused by the 0.32 caliber rubber balls dispensed from the XM99 and from auditory/visual distraction caused by the XM98. Potential injuries from employment of the 66mm NLG against individuals and crowds include injury to the eyes, skin, and internal organs of those impacted by the 0.32 caliber rubber balls and

from the unexploded submunitions. Because the XM98 and XM99 both use an auditory/visual stimulus, individuals or crowds may be at risk for some type of hearing injury from an exposure to impulse noise, as well as some type of eye injury from optical emissions.

3.0 Injury Assessment Techniques and Thresholds

Several organizations have studied blunt trauma injury to the body and several models and thresholds have been developed to predict the degree of penetration that results in injury. However, only a few of these models may be appropriate for estimating the types and severity of blunt trauma injuries likely to be caused by the XM99 projectiles, since many of the models have not been validated over a range of input parameters pertinent to the 66mm NLG projectiles (i.e. low mass and high velocity). Therefore, the predictions must be made bearing in mind the differences between the properties of the XM99 projectiles and the projectiles/impactors with which the model or threshold were developed.

3.1 Vision Damage Thresholds

Impact to the eyes by the projectiles could cause severe injury. Most likely any impact to the eye by high velocity projectiles will cause severe eye damage that may lead to a complete loss of vision in the impacted eye. Eye injury by various projectiles, including paintballs, has been studied using human cadaver and swine eyes. The results of these studies may be used to predict the severity of eye injury from impact by the 66mm NLG submunitions and projectiles.

3.2 Skin Damage

Blunt trauma from impacts by the dispensed rubber balls could cause injury to the skin and underlying tissues. Although not expected to cause any long-term disabilities, they can potentially cause visible scarring. The severity of these injuries will be strongly dependent on the range to the target, the area of the body impacted, and the thickness of clothing at the point of impact.

3.3 Internal Organ Damage

The internal organs of persons could be damaged by blunt trauma by unexploded submunitions. Based on the energy and momentum of the individual **submunition**, there is a risk of serious injury to the organs of the thorax and abdomen, as well as skull injuries. However, the risk will be strongly influenced by the range to the target, the region of the body impacted, and the number of and proximity of impacts.

3.3.1 Penetrating Trauma

There are several models and standards, which predict penetration of projectiles of different shapes. One of those models, the skin V_{50} equation, was developed by the

Ballistic Research Laboratory (BRL) to estimate penetration hazards from debris carried by the back blast of recoilless rifles.[1] The equation to estimate velocity for a 50% probability of skin penetration, V_{50} = (836 lb/ft-sec) x (A/W_f) + 72.3 ft/sec, is based upon the impact of various shaped projectiles against goatskin.[2] In this equation, A is the cross sectional area of the impactor in ft^2, and W_f is the impactor mass in lbs. The Skin Penetration Analysis reports that the V_{50} for a 0.32 caliber ball is 604 ft/sec (183 m/sec). Another model, the Total Body Model (TBM) used by Walter Reed Army Institute of Research (WRAIR), establishes 20.6 J/cm^2 as the penetration threshold. Using the TBM criteria, the impact velocity for penetration for a 0.32 caliber ball is 750 ft/sec (227 m/sec). Testing (see Section 5.2) showed that at velocities that would be obtained at the levels stipulated in the ORD, the threshold for skin penetration predicted by either the TBM or the BRL V_{50} models was not exceeded.

4.0 Applicability of Existing Blunt Trauma Thresholds and Models to 66mm NLG Submunition and Projectile Properties

Table 4-1 is a compilation of the blunt trauma thresholds currently available to estimate the lethality and injury potential of the 66mm NLG blunt trauma payload. Refer to Table 6-1 for a compilation of the injury type and threshold values calculated with the TBM for prediction of injury.

TABLE 4-1. LETHALITY/INJURY THRESHOLDS FOR BLUNT TRAUMA

Type of Effect	Threshold	Source
Fracture of Skull	33-75 ft-lbs., average 50 ft-lbs.	Swedish Institute of Research
Fracture of Facial Bones	Mandible and Maxilla 30 to 40 ft-lbs. Zygomatic Arch 4 to 10 ft-lbs.	Automotive Research
Lethality of Thorax Impact	Calculated from $(MV^2)/WD$ $P(L)=1/\{1+\exp[\alpha+\beta\ln(MV^2)/WD)]\}$	Edgewood Arsenal
Lethality of Thorax Impact	Calculated from $(MV^2)/TW^{1/3}D$ $P(L)=1/\{(1+6.645 \times e^{10})/[(MV^2)/DW^{1/3}T)^{3.597}]\}$	Edgewood Arsenal (Sturdivan Model)
Likelihood of Liver Fracture	Calculated from $(MV^2)WD$	Edgewood Arsenal
Blunt trauma	>90 ft-lbs. severe damage region 30 to 90 ft-lbs. is a dangerous region Under 30 ft-lbs. is low risk region	Land Warfare Laboratories, Human Engineering Laboratory

[1] Matoo, B. N., Wani, A. K., Asgekar, M. D. "Casualty Criteria for Wounds from Firearms with special reference to shot penetration. Part II.," *J. Forensic Sci.* **19**(3) pp. 585-589. 1974.
[2] DiMaio, V. F. M., Copeland, A.R., Besant-Matthews, P. E., Fletcher, L. A., Jones, A., "Minimal Velocities Neccessary for Perforation of Skin by air Gun Pellets and Bullets," *J. Forensic Sci.*, **27**(4), pp. 894-898, 1982.

Type of Effect	Threshold	Source
Blunt Trauma	Calculated from projectile momentum and diameter	Total Body Model, WRAIR
Blunt Trauma	Viscous Criterion, VC_{max} = 1 m/sec is 25% chance of severe injury from thoracic impact	General Motors Research Laboratory
Non-Penetration	$P = 1/[1 + e^{-(a+bx)}]$	Skin V_{50} Plots From (BRL)
Non-Penetration	Less Than 182 ft-lbs/in^2	Israeli Military Industries

Unfortunately, the Edgewood Arsenal models and the WRAIR models have not been validated with projectiles of similar mass, size, and impact velocity to the 0.4 g, 0.32 cal. 66mm NLG projectiles. They were developed for predicting injury from impacts of larger mass, slower moving impactors.

The 66mm NLG projectiles are orders of magnitude less massive, significantly smaller in diameter and impact area, with velocities an order of magnitude greater than the test impactors used to develop the Viscous Criterion. Because the 66mm NLG projectiles differ significantly from the impactors used to develop the Viscous Criterion, the threshold values of VC_{max} developed under automobile accident conditions cannot be applied to the 66mm NLG projectile impacts. The very low mass (i.e. inertia) of the 66mm NLG projectiles means that the peak in the VC curve will occur at a much smaller displacement of the impacted tissue. Since the injury is proportional to the peak in the VC curve and the peak occurs at a small displacement, it is unlikely that injury to the internal organs of the thorax will occur, provided the projectiles do not penetrate or a large number do not impact as a single cluster.

The WRAIR TBM is purely a computational compilation of different models. Projectile parameters and assumptions about the impact kinematics are used to calculate values for injury criteria. These are usually calculated from data generated with anthropomorphic simulators under simulated automobile accident conditions. The submunition momentum is used to calculate almost all of the thresholds given in Table 6-1. Because the models rely almost solely on projectile momentum, they most likely are only valid for a narrow range of kinetic energies and impact diameters. The effect of allowing kinetic energy to be unbounded and diameter to be undefined in the model severely limits its usefulness and accuracy for predicting injury from low mass, high velocity impactors such as the 66mm NLG. The TBM makes inaccurate skull fracture calculations for low mass, high velocity projectiles. When the HIC and concussion thresholds are calculated for low-mass small diameter projectiles the predictions are inconsistent with the known outcome. For example, the TBM predicts that impacts by bullets fired from 9 mm handguns will not cause concussions or skull fractures. An even closer look at how the Head Injury Criterion (HIC) and concussion thresholds are calculated using momentum and an estimate of the impact duration and elasticity shows that skull fracture, as predicted by the calculated HIC value, occurs at lower impact

velocities than mild concussions from the same impactor. For example, when the momentum of the 5.56mm NATO round is used to calculate head injury, the predictions are skull fracture and no concussion. The same inconsistencies are observed for thoracic and abdominal impacts. The lethality calculations predict a lethal effect, however, the calculations done for specific injuries predict no injury beyond skin penetration. So clearly, the TBM does not accurately predict injuries for the 66mm NLG projectiles.

The WRAIR TBM could be appropriately used to assess the blunt trauma injury potential of the 66mm NLG submunitions and other similarly sized non-lethal projectiles only after validation and verification with projectiles of similar size, mass, and velocity.

5.0 Data Collected During Development

5.1 Submunition Velocity

Impact velocities of the 66mm NLG submunitions were calculated from terminal velocity measurements during the Vertical Wind Tunnel Test and were determined to be 30m/sec at 50 meters, 22m/sec at 75 meters, and 19m/sec at 100 meters. Launch velocities were assumed to be 70m/sec. Impact angles of the submunitions for 50m, 75m, and 100m aim points were calculated to be 11°, 26°, and 56° respectively.

5.2 Projectile Velocity

The Human Effects Advisory Panel (HEAP) reports that "the program management adopted a muzzle velocity (from the submunition) of 350ft/sec (107m/sec) and an impact velocity of 290ft/sec (88m/sec) at five meters."

5.3 Accuracy and Dispersion Testing of the Projectile

To provide rudimentary modeling data for the 66mm NLG, the XM99 was detonated one foot above the ground with targets located at 10, 20, and 30 meters from ground zero. Fifteen rounds (submunitions), each containing approximately 140 0.32 caliber PVC balls, were detonated at each range. The target was a 4' x 8' and 0.5" thick sheet of Styrofoam and was located forward of the ammunition. Three silhouettes were used per target location. Table 5-1 is a reproduction of Table 2 in the Final Report of the Accuracy/Dispersion Test. Note: the data in Table 5-1 is from *one* exploded XM99. A typical grenade will probably contain <u>three</u> XM99s. Thus, it is expected that the effects will be additive and the number of hits to the target will be higher than what is represented.

Table 5-1

TABLE 2. 66-MM NON-LETHAL ACCURACY/
DISPERSION RESULTS

Cartridge Type	Range[a], m	Silhouette Position and Area of Body Part Hits[b]											
		Left Side				Center				Right Side			
		1	2	3	4	1	2	3	4	1	2	3	4
66-mm	10	2	2	3	3	2	2	4	3	2	2	2	3
	20	1	1	-	2	2	2	5	5	1	1	-	3
	30	1	-	3	1	1	1	2	1	2	2	-	3

[a]Fifteen rounds were fired at each range.
[b]Three silhouettes placed side by side were used.

1 = Head/neck.
2 = Chest.
3 = Abdomen.
4 = Extremities.

5.4 Accuracy and Dispersion of the Submunition

Statements about the accuracy and dispersion of the submunition can be made from the Charts Depicting Predicted Impact, Actual Impacts, and Roll Distances for the XM315 LVOSS Installation Kit. The dispersion plots at each of the 100-meter trials showed a tighter lateral and longitudinal dispersion pattern than each of the 75 and 50-meter trials. When the launch angle was set to impact at 100 meters, submunitions had recorded impacts between 100 and 140 meters, which is almost 40 meters beyond the aim point. When the launch angle was set to impact at 75 meters, submunitions had recorded impacts between 75 and 105 meters, which is almost 30 meters beyond the aim point. When the launch angle was set to impact at 50 meters, submunitions had recorded impacts between 50 and 85 meters, which is about 35 meters beyond the aim point.

Additionally, the Final Test Report of the Non-Lethal Joint Operational Excursion (JOE) states that of the 95 total rounds of XM98-99 that were fired, "Soldiers and Marines collectively managed to hit their intended range with LVOSS Adjustable Elevation Bracket 41 times and missed their intended target 54 times." These data suggest increased possibility of submunition impacting the target or bystanders (unintended collateral damage).

6.0 66mm NLG Injury Analysis

To estimate the types of and severity of injuries that may result from impacts by the 66mm NLG, the following parameters were used: submunition mass = 125g, submunition diameter = 6.29cm, projectile diameter = 0.32 inch, projectile mass = 0.4g,

number of balls per munition/canister = 140, and an impact velocity of 429ft/sec (130m/sec). Note that an impact velocity of 130m/sec is above the program management accepted average muzzle velocity (107m/sec). However, for target safety analyses, this higher muzzle velocity was used as data inputs to the TBM to be indicative of a worst-case scenario and representative of maximum risk to the target.

6.1 Blunt Trauma Hazard of the 66mm NLG Submunition

Based on the information gathered on the accuracy and dispersion of the submunition, there is a risk of blunt trauma from unexploded submunitions. According to a briefing by Dr. Jeff Widder to the HEAP, there is a 21% chance of slight lung contusion, a 1% chance of a skull fracture at 50 meters, and a 1% chance of causing mandibular fractures at 50, 75, and 100 meters. Furthermore, the Health Hazard Analysis (HHA) states that the TBM predicts possibility of skull injuries, moderate lung contusion, ventricular fibrillation, and liver laceration at distances less than 60 meters. At distances greater than 60 meters, only mandibular fracture and trace to slight lung contusion is expected.

Dr. Widder's Eye Injury Analysis depicts a 10% likelihood of impact by a single unexploded submunition on a person's torso, head, or neck at an average spacing of 7 feet. This percentage increases as the average spacing decreases.

TABLE 6-1 WALTER REED ARMY INSTITUTE OF RESEARCH TOTAL BODY MODEL (V 1.02) PREDICTIONS FOR INJURY BY IMPACT OF THE 66MM NLG SUBMUNITION.*

Type of Injury	Threshold	Calculated Value
Head		
Cerebral Concussion I	V_{max} = 2.70 m/sec	2.04 m/sec
Cerebral Concussion II	V_{max} = 4.90 m/sec	2.04 m/sec
Diffused Axonal Injury	V_{max} = 6.20 m/sec	2.04 m/sec
Skull Fracture	HIC = 450	623
Mandible Fracture	F_{max} = 1780 N	6432 N
Thorax		
Severe Lung Contusion	Work = 0.0195 $kg{\cdot}m^2/sec^2$	0.0090 $kg{\cdot}m^2/sec^2$
Fracture of Ribs (1%)	VC_{max} = 0.28 m/sec	0.39 m/sec
AIS > 4	VC_{max} = 0.38 m/sec	0.39 m/sec
Heart Lesion (1%)	VC_{max} = 0.50 m/sec	0.39 m/sec
Heart Rupture (1%)	VC_{max} = 0.64 m/sec	0.39 m/sec
Ventricular Fibrillation	V_{max} = 10.70 m/sec	12.08 m/sec
Lethality (1%)	S = 8.21	S = 7.97
Abdomen		
Liver Laceration (1%)	VC_{max} = 0.72 m/sec	1.96 m/sec
Lethality (1%)	S = 8.86	S = 7.97
Penetration		
Skin	E/A = 20.58 J/cm^2	6.50 J/cm^2

* Input parameters for the model: target mass = 70 kg, target wall thickness = 4.000 cm impactor mass = 125.0 g, impactor diameter = 6.290 cm, I/MV = 1.500, impact duration = 1.000 ms

6.2 Penetration by 66mm NLG Projectile (Excluding Eyes)

When possible, it is best to compare data collected on projectiles of similar mass, diameter, shape, and hardness to that of the rubber balls dispensed by the XM99 Grenade. For estimating the likelihood of penetration, the "worst case" velocity is assumed. Using the BRL Skin V_{50} equation, V_{50} = (836 lb/ft-sec) x (A/W_f) + 72.3 ft/sec, the predicted velocity for penetration of the bare skin 50% of the time is 604 ft/sec (183 m/sec). The BRL equation is used since it is conservative and predicts the lowest penetration velocity of any of the penetration models. One can see that with all the worst-case assumptions, there is a minimal probability of penetration. The ORD states that the target would be wearing a single layer of clothing, further decreasing the likelihood of injury to the target. Since the cross sectional density of the rubber balls is less than that of the projectiles used to develop the V_{50} equation, any deviation should be towards an underestimate of the penetration threshold velocity by the model, further supporting the prediction of non-penetration.

It should also be noted, though, that the criteria used for penetration was the breaking of the surface of either isolated human or goat skin or skin simulant prepared from 20% ballistic gelatin. It was assumed that any projectile that broke the skin would have sufficient velocity to penetrate tissue and cause a serious wound. The basis for this assumption is unclear. However, it is not clear that breaking isolated skin, stretched over a frame is the same as penetrating through skin connected to and supported by living tissue. Breaking the skin does not indicate that penetration beneath the skin into deep tissue will always occur. Data on .32 cal projectiles, with similar velocities, hitting live tissue similar to human tissue are limited. In the light of the other thresholds developed from cadaver testing, to be discussed, it might be best to consider the V_{50} (183m/sec) a conservative threshold for breaking the skin, but not necessarily penetration into underlying tissue. This breaking of the skin or abrasion of the skin may also pose a health risk if not treated to prevent infection.

The WRAIR TBM penetration threshold of 20.6 J/cm^2 is a more reasonable threshold to use for determining the likelihood of penetration since it is based on experimental results with rounded projectiles. The TBM uses the criteria of DiMaio,[3] which are in agreement with experimental results of previous studies with rounded projectiles fired against cadaver thighs. Journee showed that 8.5 g, 11.25mm diameter lead spheres required an energy density of 21.3 J/cm^2 to penetrate the skin of cadavers.[4] Matto et al. used 4.5 g, 8.5mm diameter lead spheres and showed that the

[3] DiMaio, V. F. M., Copeland, A.R., Besant-Matthews, P. E., Fletcher, L. A., Jones, A., "Minimal Velocities Neccessary for Perforation of Skin by air Gun Pellets and Bullets," *J. Forensic Sci.*, **27**(4), pp. 894-898, 1982.
[4] Journee, C. Rapport "Entre Force Vive Des Balles at la Gavite des Blessures qu'elles peuvent causer," *Rev. d'Artilleries*. **70**(1) pp. 81-120, 1907.

energy density required to penetrate cadaver thighs was 20.6 J/cm^2.[5] DiMaio's threshold is identical to that of Matto, however, the testing he did with round nose .38 caliber lead bullets (.38 caliber lead bullets have a diameter of just over 9 mm.) showed penetration of cadaver thighs at 19.5 J/cm^2. In order to have an energy density of 20.6 J/cm^2 the 0.32 cal PVC balls need to have an impact velocity of 227 m/sec (750 ft/sec). Since the rubber balls are more compliant than the lead spheres used to develop this threshold (i.e., the 20.6 J/cm^2), one would expect a lower chance of penetration than predicted by the model. Clothing worn by the persons in the crowd will also aid in decreasing the chance of penetration by those projectiles. It is unlikely that impacts by the dispensed rubber balls will penetrate into tissues below the skin (excluding impacts to the eyes, which are more susceptible to penetration than other areas of the body). Environmental temperature induces changes in cutaneous/peripheral vascularization, which may alter susceptibility to penetration, particularly in the elderly. However, the fraction of those individuals in the crowd is likely to be small.

6.3 Blunt Trauma Hazard of the 66mm NLG Projectile

Impact by the 0.32 cal. rubber balls/projectiles dispensed by the XM99 Grenade is not likely to penetrate the skin and thus, any induced trauma can be classified as blunt trauma. Table 6-2 shows how the calculated values of impact energy relate to the appropriate thresholds shown in Table 4-1.

TABLE 6-2 CALCULATED IMPACT ENERGIES OF THE 66MM NLG PROJECTILES COMPARED TO APPROPRIATE HISTORICAL THRESHOLDS.

Type of Effect	Threshold	0.32 cal Rubber Ball with Impact Velocity of 130m/sec
Fracture of Skull	33-75 ft-lbs., average 50 ft-lbs.	2.5 ft-lbs.
Fracture of Facial Bones	Mandible and Maxilla 30 to 40 ft-lbs. Zygomatic Arch 4 to 10 ft-lbs.	2.5 ft-lbs.
Lethality of Thorax Impact	Calculated from $(MV^2)/WD$ $P(L)=1/\{1+\exp[\alpha+\beta\ln(MV^2)/WD)]\}$	≤0.0005
Lethality of Thorax Impact	Calculated from $(MV^2)/TW^{1/3}D$ $P(L)=1/\{(1+6.645 \times e^{10})/[(MV^2)/DW^{1/3}T)^{3.597}]\}$	≤0.0005
Liver Fracture	$414 \leq$ 50/50 zone ≤ 1451	≤298
Blunt trauma	>90 ft-lbs. severe damage region 30 to 90 ft-lbs. is a dangerous region Under 30 ft-lbs. is low risk region	2.5 ft-lbs.

[5] Matoo, B. N., Wani, A. K., Asgekar, M. D. "Casualty Criteria for Wounds from Firearms with special reference to shot penetration. Part II.," *J. Forensic Sci.* **19**(3) pp. 585-589. 1974.

Type of Effect	Threshold	0.32 cal Rubber Ball with Impact Velocity of 130m/sec
Blunt Trauma	Calculated from projectile momentum and diameter	See Total Body Model, WRAIR Table 6-2
Penetration	20.6 J/cm^2	6.8J/cm^2

The WRAIR TBM does not predict any kind of blunt trauma injury from impacts by the XM99 Grenade projectiles. It does not consider synergism of multiple impacts by the 66mm NLG submunitions.

There are no thresholds for injury exceeded in Table 6-2. The only threshold that comes close is that for fracture of the zygomatic arch. This, of course, excludes those injuries not covered in the table, in particular impacts to the eyes. Multiple impacts at the expected impact velocities likely will not cause a significant increase in the likelihood and severity of injury predicted by the models.

Table 6-3 below lists energy densities at different velocities compared to the skin penetration threshold. Where data were collected, the highest recorded impact velocity of a single 0.32 cal projectile was 168m/sec at 0.6 meters. The energy density at this velocity was calculated to be 11.3 J/cm^2, which is approximately half of the energy density required for skin penetration predicted by the TBM for 4.5 g, 8.5mm diameter lead spheres[3] .

TABLE 6-3 CALCULATED IMPACT ENERGIES OF THE 66MM NLG PROJECTILES AT DIFFERENT VELOCITIES.

	Velocity (ft/sec)	Velocity (m/sec)	Energy Density (J/cm^2)	Distance (m)	Source
Skin Penetration Threshold	750	227	20.6	--	TBM
Skin Penetration Threshold (V_{50})	604	183	13.4	--	BRL
Muzzle Velocity	552	168	11.3	--	Veridian Engineering data
Impact Velocity	429	130	6.8	--	Widder: Table 6-2
Muzzle Velocity	350	107	4.5	--	HEAP report
Impact Velocity	290	88	3.1	5.0	HEAP report

6.4 Eye Impact Hazard from the 0.32 Cal. Rubber Balls

Impact to the eyes could cause a severe eye injury that may result in complete loss of vision and require medical removal of the eye. The energy density for eye penetration of round spheres is 6 J/cm^2 +/- 1.5 J/cm^2. To achieve this density for the 0.32 caliber balls, an impact velocity of 123m/sec (406ft/sec) is required, which is above the program management adopted impact velocity (88m/sec) at 5 meters. The eye penetration energy density of 6 J/cm^2 is also above the energy density of 4.7 J/cm^2 associated with the program management adopted muzzle velocity of 107m/sec.

Velocity is not the only parameter that influences the likelihood of penetration and injury by impact. The mass, diameter, shape, and hardness of the impactor also strongly influence the physiological damage that may result from a projectile impact. At constant velocity and diameter, the injury potential of an impactor increases with mass. At constant velocity and mass, the penetration potential and injury increase with decreasing projectile cross sectional area ($0.25\ \pi D^2$). The hardness of the projectile also influences how it interacts with the body and the likelihood of penetration. Hard projectiles tend to have better penetration characteristics than compliant projectiles; for the case of non-penetrating impacts, hard projectiles tend to be more damaging than compliant projectiles.[6] There is more energy transfer to the impact area, thus, more potential for damage.

If we consider a paintball and a 0.32 cal PVC sphere from the XM99 to have the same impact velocity of 300ft/sec (91m/sec, which slightly exceeds the program management adopted impact velocity of 88m/sec), we can compare their relative potentials to penetrate and do damage by looking at the ratio of their mass to diameter (assuming we neglect hardness and difference in the contours). The ratio of the mass to the square of the diameter of the 0.32 cal PVC sphere is ($0.4g/0.81cm^2$) = $0.61g/cm^2$ and the ratio of the mass to the square of the diameter of a paintball is ($3.55g/1.75cm^2$) = $1.16g/cm^2$. This means that the kinetic energy per cm^2 of impact area of a paintball is greater than that of the 0.32 cal PVC sphere when both have an impact velocity of 300 ft/sec (91m/sec). Based on this, one would expect the penetration and tissue damage (directly under the impactor) caused by the 0.32 cal PVC sphere to be less than that caused by a paintball. However, the velocity of the PVC spheres may exceed 300ft/sec (91m/sec). With an impact velocity of 429ft/sec (130m/sec), the 0.32 cal PVC sphere has about 10% more kinetic energy per mm^2 of cross sectional area than that required for a 4.5 mm steel BB to rupture the human eye globe.[7,8] At impact velocities close to 300 ft/sec (91m/sec), one would expect the 0.32 cal PVC to cause similar, although

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[6] Egner D. O., "The Evaluation of Less-Lethal Weapons," U.S. Army Human Engineering Laboratory Technical Memorandum 37-77, December 1977.

[7] Delori, F., Pomerantzeff, O., Cox, M. S., "Deformation of the Globe Under High Speed Impact: Its Relation to Contusion Injuries," *Invest Ophthalmol,* **8**, pp. 290-301, 1969.

[8] Preston, J. D., "Review of Standard Consumer Safety Specification for Non-Powder Guns (ANSI/ASTM F589-78) and Non-Powder Gun Projectiles and Propellants (ANSI/AATM F590-78)," Mechanical and Textile Division, Engineering Sciences, CPSC, Washington, Feb 8, 1980.

probably less severe, eye injuries than have been reported for paintball impacts to human eyes. These values are consistent with work done by Stewart[9], who concluded that eye penetration by small spheres occurred at an impact energy density of 6 J/cm^2 +/- 1.5 J/cm^2. At an impact velocity of 91m/sec, the 0.32 cal spheres (projectiles) have approximately 3.3 J/cm^2, which is lower than the impact energy density required for eye globe penetration. According to the Eye Injury Analysis, rupture or penetration of the eye globe by 0.32 cal PVC could result in loss of the eye and is likely to occur from eye impacts at ranges less than 10 meters. However, there are virtually no data available on impacts at ranges less than 10 meters.

6.4.1 Eye Impact Probability Model

If we make a few assumptions, we can estimate the probability of eye impacts from the projectile. Although eye impact will not always result in the loss of the eye, the resulting trauma will likely cause a severe injury that may cause residual eye complications.

To estimate the probability of eye impacts, we first consider the case of an isolated eye with a vulnerable cross section of 1 in^2 being impacted by a sphere. For this case, the probability of the eye being impacted is equal to the spatial density of spheres/in^2 (assuming each sphere passes through a unique 1 in^2 area in the plane of the eye perpendicular to the path of the sphere.) When the spatial density of spheres is 1 sphere/in^2, the probability of the eye being impacted is 1.0. When the spatial density of spheres is 0.5 spheres/in^2, the probability of the eye being impacted is 0.5. The probability of the isolated eye being impacted is then used to calculate the probability of eye impacts for 2 eyes, which represents the probability of a single person viewing the munition being impacted in the right eye, the left eye, or both eyes. The probability of a single person being impacted in the eyes is then used to calculate the probability of multiple persons being impacted in the eyes. If we assume that the spatial density in the region of the eyes is constant (using the average spatial density from arena testing or an estimate of the spatial density) and that no more than one sphere/in^2 passes through the plane of the eyes (for the case when arena test data have multiple impacts in a single square inch area those impacts will be considered to be from a single projectile) we can calculate the probability of eye impacts for groups using the Equations 1 and 2.

Equation 1:

$$\% P = 100 \times \frac{1 + [\, a(p-1)^{n-1} + b(p-1)^{n-2} + c(p-1)^{n-3} \ldots + \ldots z(p-1)^{(n-(n-1))} \,]}{(p)^n}$$

Equation 2:

$$p = 1/[(1 + 2(p_e - 1))/(p_e)^2\,]$$

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[9] Stewart, G. M., "Eye Protection Against Small High-Speed Missiles,) *J.Ophth.*, **51**, pp 51-80, 1961

Where:

- P = the probability of eye strikes for the group of n persons. It is the summation of the probabilities for the all the possible permutations of eye impacts that can occur for the 1 to n persons in the group.
- n = number of persons exposed to and facing the shooter.
- a, b, c,...z are the number of permutations for the case of 1 person, 2 persons, 3 persons,...n-1 persons being impacted in the eyes. The number of permutations for the cases of multiple persons being impacted follows Pascal's triangle were the two number 1s represent the number of permutations for the case of all persons and none of the persons being impacted in the eyes, a is always equal to n, the number of persons, and is the second number from the left in the n^{th} row of Pascal's triangle.
- p = the inverse of the probability of eye strikes for a single person facing the shooter.
- p_e = the inverse of the probability of a single impact to an isolated eye = inverse of the spatial density of spheres in spheres/in^2

In the expression for %P, the term $1/(p)^n$ is the probability that all n persons will be impacted in one or both eyes, for large groups this term is usually very small. The term $a(p)^{n-1}/(p)^n$ is the probability that 1 person will be impacted in one or both eyes. The term $b(p)^{n-2}/(p)^n$ is the probability that two persons will be impacted in one or both eyes and so on until the term $z(p)^{(n-(n-1))}/(p)^n$ which is the probability that all but one person will be impacted in one or both eyes. The term $(p)^n$ is related to the probability per individual person of an impact to the eyes in a group of n persons, where the total number of permutations of single and multiple person eye impacts (none, one or both eyes) for the n persons is 2^n.

Because arena testing is not yet completed at the time of this writing, some assumptions about the main spray of the submunitions must be made. We can assume two orientations for the submunitions when they burst: it will either be standing on end or lying on its side. We can also use estimated sphere spatial densities to calculate the percent probability of eye impacts for various numbers of persons facing the munition from various distances

Based on Dr. Widder's Eye Injury Analysis, if the submunition bursts while standing on its end, a child has a 2% chance of an eye impact by the projectile at 5ft. (1.5m), while a group of ten children have an almost 20% chance that one of them will suffer an eye impact. An adult, however, has less than a 1% chance of an eye impact by the projectile at 10ft. (3m), while a group of 10 adults have just over a 6% chance that one of them will suffer an eye impact. If the submunition bursts while lying on its side, a child has a 6% chance of an eye impact at 1.3ft. (0.4m). At the same distance, the risk exceeds 35% for a group of 10 children. An adult, however, has a 2% chance of an eye impact at the same distance, while the risk is almost 18% for a group of 10 adults. Children's eyes are closer to the origin of the main spray of the submunition

when it is lying on its side or on end. At these short ranges and short elevations from the ground, the spatial density of spheres is high.

6.5 Optical Emission Hazards

As previously mentioned, the XM98 submunition uses an audio and visual stimulus to achieve its desired effect. The visual stimuli can pose a risk to the target. The Health Hazard Assessment Report on the 66mm NLG states that the XM98 can cause corneal and skin injuries at close range when improperly used, but was not capable of causing permanent retinal injury or temporary flash blindness, at any distance. The report further noted that during optical emission testing, a potential for serious target population injury from high velocity debris was observed. However, no data were presented or collected to support that proposal.

6.6 Pain and the 66mm NLG Projectiles

Pain from blunt impact is the principle mechanism through which the XM99 grenade is expected to achieve crowd dispersal, but do the 0.32 cal PVC projectiles actually cause pain? To answer that, the Naval Fleet Training Center (NFTC) was contacted by the Mission Research Corporation (MRC) to identify the conditions used for training security personnel using paintball guns. The pain threshold levels the NFTC uses are the same thresholds that the MRC used for their research: mild pain threshold velocity of 185ft/sec (56m/sec) and the significant pain threshold velocity of 240ft/sec (73m/sec). MRC then used the same paintballs as the NFTC, as well as other Government supplied projectiles, and conducted gelatin tests at velocities between 155 and 300 ft/sec (47-91m/sec). They also varied the thickness of the target. A time resolved pressure wave was recorded at the target rear surface (resolution = 0.2u sec). These experiments showed two consistent waveform characteristics – the peak pressure related to the first transient, and the rise time to the peak. The peak pressure was also linearly related to the striking velocity. They also found that most of the energy content associated with the projectile-target interaction is contained within the first peak. This led to their working hypothesis that the peak pressure of the first transient and the rise time to this peak governs mechanically induced pain, which is supported by the following: the stress state for an viscoelastic material such as biological soft tissue will be a function of strain-rate, which in this case is the analogue of the rise time.

According to The Interim Report by the MRC, the threshold impact velocity for pain for the 0.32 cal PVC balls is between 240 and 250ft/sec (73 and 76m/sec). The expected impact velocity for an XM99 projectile is 290ft/sec (88m/sec). Using the MRC pain threshold results, the projectile from an XM99 is expected to cause mild, not significant, pain.

Figure 6-1, below, is a summary of the pain threshold results for the various projectiles used and is reproduced from the MRC Interim Report.

FIGURE 6-1: PAIN THRESHOLDS OF VARIOUS PROJECTILES (MRC INTERIM REPORT)

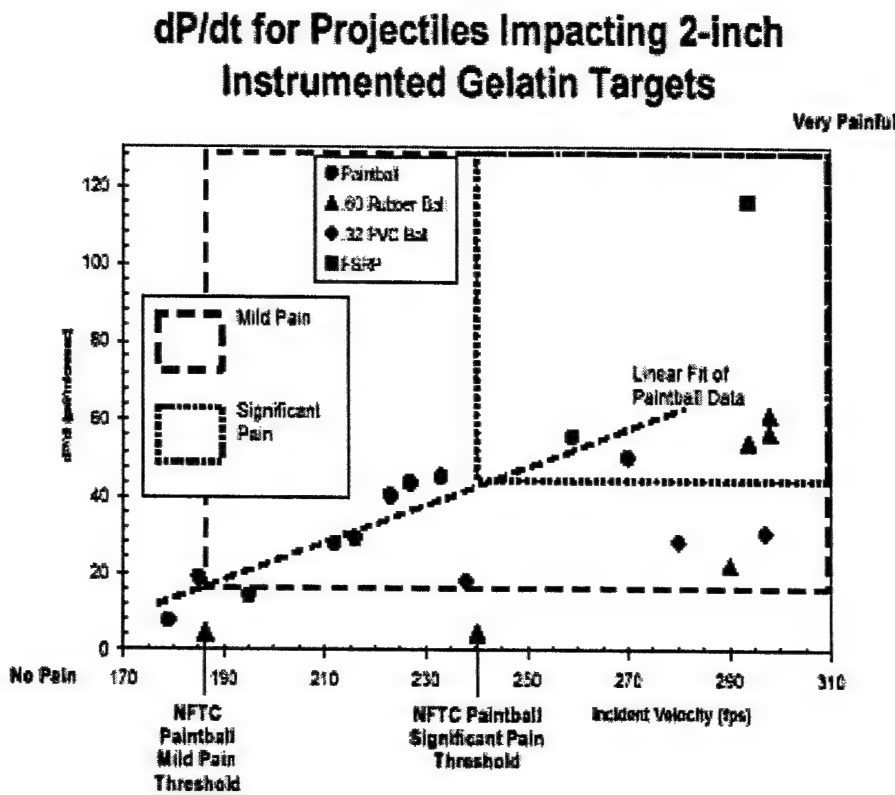

FIGURE 1-5. Pain Thresholds in terms of the Ratio of the Rise time and Peak Pressure for the First Transient versus Projectile Striking Velocity using 2-inch Targets

6.7 Effectiveness Testing with .32 caliber projectiles

The objective of this study, funded by the Joint Non-Lethal Weapons Directorate and the program managers of the MCCM, 66mm, and 40mm NLW programs, was to experimentally determine, using the "up-down" method, an "effective dose" (in terms of velocity) for stopping 50% of the subjects from performing a goal-directed behavior (ED50) with a single impact of a .32 caliber PVC ball as used in the MCCM and the 66mm NLG. The experimentally determined "effectiveness" velocity can then be compared to field velocity measurements or calculations to see if the munitions are "effective" at the ranges stated in the Operational Requirements Document (ORD). For this experiment, swine were used, an animal of similar mass and skin physiology to the human. The impact point on swine was front flank. The goal-directed task was a bar pressing task for a food reward. Animals were initially trained, exposed to the sound of compressed air launcher without a projectile to eliminate (habituate) a neophobic response, and then exposed to a single projectile at a measured velocity. Figure 6-2 shows the experimental setup; the launcher barrel is approximately 2 feet from the impact point on the pig with the chronograph in between. From a pilot study with 3 pigs

and multiple single impacts spaced temporally over a period of a couple of weeks, a reasonable work stoppage duration criteria was estimated to be about 15 seconds. This criterion was used for ED50 determination. The criteria was applied as follows: If the subject stopped bar pressing for >15 seconds when impacted with a projectile at a given velocity step, then the launcher was set to the next lowest velocity step; if the subject stopped bar pressing for <15 seconds, then the launcher was set to the next highest velocity step.

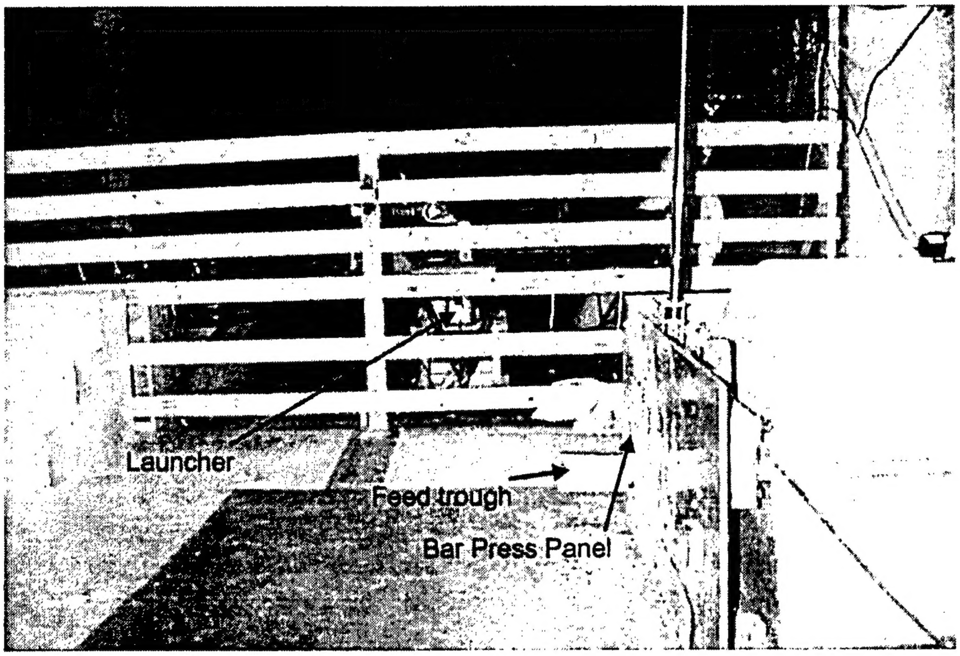

Figure 6.2. ED50 and pilot study set-up. Distance between muzzle and target (swine) is approximately 3.25 ft (97 cm).

The study showed several target effects. First, a single projectile with a "muzzle" velocity up to that produced by the 66mm (~500 ft/sec) did not cause work stoppage for the criterion of 15 seconds. Table 6-4 shows the observations from the ED50 study. Second, a pilot study, designed to help determine the range of velocities to look at in reaching a reasonable estimate of work stoppage duration, showed that multiple exposures to a single projectile, spaced over some time period, could produce a work stoppage. This suggests that both the 66mm and the MCCM may not be effective with one use and that it will take multiple projectile impacts on the target (spaced either temporally or spatially) to physically change a behavior. Third, at velocities of ~330ft/sec (~101m/sec), the projectiles produced abrasions on the skin of swine that bled and took several days to a couple of weeks to heal. This velocity corresponds to an energy density of ~4.1J/cm^2. Figure 6.3 shows the abrasions of various ages.

Table 6-4. Projectile velocities and target responses for ED50 study.

SUBJECT #	PSI	FT/SEC	OBSERVATIONS
1	45	405	Slight flinch did not stop eating.
2	50	428	Moved away from Bar Pressing for 2 seconds, and then went back to eating.
3	55	439	Walked away from Bar Pressing for 3.7 seconds, and then went back to eating.
4	60	459	Did not even take head out of feeder, kept eating.
5	65	471	Had a small flinch, stopped eating for 1.9 seconds then went back to Bar Pressing and eating.
6	70	485	Small flinch, stopped for 4.5 seconds then went back to Bar Pressing and eating.
7	75	496	Did not even take head out of feeder, kept eating.
8	80	505	Very small flinch but did not stop eating, did not take head out of feeder.
9	100	552	Flinched, stopped for 2 seconds then went right back to Bar Pressing and eating.
10	100+	610	Did not even take head out of feeder, kept eating.

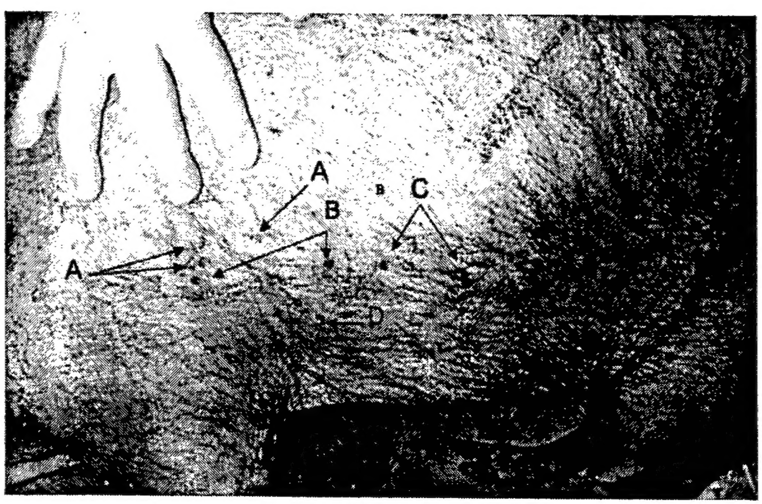

Figure 6-3. The lesions at A were made by a 32 cal pellet with the air gun set at 85 psi (~508 ft/sec). The lesions at B and C were caused by pellets fired at 35 psi (~372 ft/sec) and 45 psi (~409 ft/sec), respectively. The lesions at B and C were created 4 days earlier. The lesion at D was created 12 days earlier.

6.8 Exposure to Impulse Noise

As previously mentioned, both the XM99 and the XM98 submunitions use auditory and visual stimuli to achieve their desired effect. The auditory stimuli can pose a risk to the target. The Health Hazard Assessment Report on the 66mm NLG states that a single unprotected exposure to impulse noise at 167dBP has an estimated 1% risk of sustaining permanent hearing loss. Exposures from 167 to 177 dBP are estimated to produce a 4% risk. Above 177 dBP, a greater but unknown risk is likely. Tests conducted by the U.S. Army Center for Health Promotion & Preventive Medicine determined that the impulse noise from an exploded submunition was between 158 to 162 dB at a distance of 20ft. (6m), thus, yielding less than a 1% risk of sustaining permanent hearing loss.

7.0 Conclusions

The WRAIR TBM is the sanctioned model for prediction of non-lethal weapons blunt trauma effects. This model predicts injuries from impacts to the head, face, thorax, and abdomen (see Table 6-1). The energy and momentum of the 66mm NLG projectiles have been used to estimate the likelihood of skin penetration and blunt trauma injury from impacts to the head, thorax, abdomen and eyes. The greatest risk from employing the 66mm NLG is a blunt trauma impact by the unexploded submunition. It is very likely that someone in the crowd will be impacted. Bearing this in mind, the injuries outlined by WRAIR become quite relevant. However, the likelihood of penetration is believed to be low, based on comparison of the projectiles' energy density to that of penetrating projectiles of similar size and penetration thresholds developed by the BRL.

The models used also do not cover injury to the eyes. Predictions of eye injury from impacts by the 66mm NLG projectiles were based on the comparison of the projectile properties to objects known to cause serious eye injury. The analysis indicates rupture of the eye globule (from direct impact of the projectile) that will lead to complete loss of vision and probably removal of the eye is likely, although the energy and momentum of the projectiles is below that of other similarly sized objects that will rupture the eye globe. However, the projectiles per se, will not likely penetrate the eye. Eye injuries such as detached retinas, corneal abrasions, and scarring can occur from impacts that do not rupture the eye globule. These injuries may result in chronic problems and partial and sometimes complete loss of vision may result.

Apart from eye impacts, the 66mm NLG, as a whole, has a relatively low probability of causing permanent and/or serious injury (within the constraints of the models used). Hence, from a system performance and safety aspect, it is likely to perform as prescribed in the ORD. However, from a target effectiveness standpoint, some initial studies suggest that the 66mm NLG **projectile** (i.e. the 0.32 caliber PVC ball) may only be marginally effective at producing pain and may not be capable of stopping a goal-oriented task for up to 15 seconds (at a single dose). More testing is

suggested to determine the effect of multiple projectile impacts to the target and whether the ORD requirements will be met in regard to type and duration of effect on the crowd. In addition to collecting the effectiveness data so that one can weigh effectiveness vs. risk for the 66mm NLG, additional arena testing is necessary to assess the usefulness and potential for injury of the weapon.